CLAIMS

1. A probe apparatus for sensing the position and orientation of a probe included in said probe apparatus, the probe apparatus comprising:

a probe;

a first joint member coupled to said probe and providing two degrees of freedom to said probe;

a first linkage rotatably coupled to said first joint member at a first end of said first linkage;

a second joint member rigidly coupled to a second end of said first linkage and providing one degree of freedom to said probe;

a second linkage rigidly coupled to said second joint member at a first end of said second linkage;

a third joint member rotatably coupled to a second end of said second linkage, said third joint member providing two degrees of freedom to said probe;

a support base coupled to said third joint member for supporting said probe apparatus; and

a plurality of transducers coupled to said probe apparatus, wherein each of said transducers provides angular signals for one of said degrees of freedom, wherein said angular signals from said plurality of said transducers defines a given position and orientation of said probe.

2. A probe apparatus as recited in claim 1 wherein said probe apparatus is operative to provide angular data describing a three-dimensional object to said computer system.

3. A probe apparatus as recited in claim 2 wherein said probe is a stylus.

4. A probe apparatus as recited in claim 2 wherein said first linkage and said second linkage are unable to rotate about a longitudinal axis extending through the center of each of said first linkage and said second linkage.

5. A probe apparatus as recited in claim 4 wherein said linkages are made of graphite.

6. A probe apparatus as recited in claim 5 further comprising an electronics interface electrically coupled to said sensors for providing said angular signals from said sensors to a computer system.

7. A probe apparatus as recited in claim 2 wherein said electronics interface is included within a housing of said support base.

8. A probe apparatus as recited in claim 2 wherein said joint members include a multistage stop joint which is operative to provide over 360 degrees of rotational movement about an axis.

9. A probe apparatus as recited in claim 4 wherein said transducer for one of said degrees of freedom provided by said first joint member is positioned in said second joint member.

10. A probe apparatus as recited in claim 4 wherein said first joint member provides three degrees of freedom to said probe.

11. A probe apparatus as recited in claim 1 wherein said third joint member includes a weighted end for providing a counterbalancing weight to said first and second joint member and said first and second linkages.

12. A method for calibrating a probe apparatus which provides three-dimensional position and orientation data to a computer system, said probe apparatus including a probe coupled to a mechanical linkage assembly including a plurality of joints, said mechanical linkage assembly being supported by a support base, wherein said probe is moveable within a selected volume, and wherein sensors coupled to said mechanical linkage assembly are operative to sense joint angles related to a position and orientation of said probe and joint angle data to said computer system, the method comprising the steps of:

(a) sampling a plurality of orientations of said probe as said orientation of said probe is varied at an arbitrary point within said selected volume, wherein a position of one end said probe remains fixed while said orientation of said probe is varied, said plurality of orientations being sampled from data provided by said sensors;

(b) determining spatial coordinates for said probe at each of said sampled orientations of said probe;

(c) determining error values between said spatial coordinates of said sampled orientations; and

(d) optimizing said probe apparatus by determining calibration parameters based on said error values and using said calibration parameters when determining said position and orientation of said probe in normal usage.

13. A method as recited in claim 12 further comprising a step of loading previous calibration parameters from a memory device.

14. A method as recited in claim 13 wherein said step (d) adjusts said previous calibration parameters based on said error values.

15. A method as recited in claim 14 wherein said previous calibration parameters are nominal calibration parameters with assumed ideal values when said probe apparatus is first being calibrated.

16. A method as recited in claim 15 wherein said adjusted calibration parameters are stored such that said calibration parameters may be later retrieved and used during operation of said probe apparatus.

17. A method as recited in claim 16 wherein said adjusted calibration parameters are stored on an EPROM memory device, said EPROM memory device being unable to store data over previously written data stored in said EPROM memory device.

18. A method as recited in claim 17 wherein said adjusted calibration parameters are stored as a most recent set of calibration parameters in a specific section of said EPROM memory device such that, when said calibration parameters are retrieved during operation of said probe apparatus, only said most recent set of calibration parameters are retrieved.

19. A method as recited in claim 18 wherein said EPROM memory device is positioned within said support base.

20. A method as recited in claim 12 further comprising a step of repeating said steps (a), (b), and (c) when the stylus is placed at a different position in said selected volume and using said plurality of sampled orientations from both of said positions when determining said error values.

21. A method for zeroing transducers of a probe apparatus of a three-dimensional coordinate measuring system, said probe apparatus including a linkage arm assembly having a probe positioned at a first end, a support base positioned at a second end, and a plurality of joints positioned between said probe and said base, said joints being coupled to a plurality of sensors operative to measure an angle differential before and after movement of linkages of said arm assembly connected by said joints, the method comprising the steps of:

placing said probe in a receptacle positioned on said probe apparatus, said receptacle being positioned at one of said joints or one of said linkages of said probe apparatus, wherein said linkage arm assembly can be in only one possible configuration while said probe is positioned in said receptacle, said one possible configuration being a home position;

receiving an indication to zero said sensors of said probe apparatus; and

assigning starting angles to said sensors when said probe apparatus is in said home position, said starting angles providing a zero angle reference for said sensors.

22. A method as recited in claim 21 wherein said probe is a stylus.

23. A method as recited in claim 22 wherein said starting angles have previously been calibrated for said particular probe apparatus.

24. A method as recited in claim 21 wherein said indication to zero said sensors includes receiving electrical power for said probe apparatus.

25. A method as recited in claim 21 wherein said receptacle comprises a shallow divot.

26. A rotary table for use with a three-dimensional digitizing system, said digitizing system including a probe apparatus for measuring three-dimensional coordinates from an object resting on said rotary table, the rotary table comprising:

a support base;

a turntable coupled to said base and operative to rotate about an axis positioned perpendicularly to a surface of said turntable; and

a sensor coupled to said support base and operative to measure an angular rotation of said turntable, wherein said sensor provides a signal indicative of said angular rotation to a host computer system, said host computer system being operative to include said angular rotation of said turntable in a determination of the position and orientation of a probe with respect to an object on said rotary table of said probe apparatus when said probe is proximate to said object, said angular rotation being included in said determination when said probe has contacted said object before and after said turntable has been rotated.

27. A rotary table as recited in claim 26 wherein said rotary table further includes interface electronics for providing said angular rotation to said host computer.

28. A rotary table as recited in claim 26 wherein said sensor is positioned near the center of said turntable, and wherein a shaft of said sensor is coupled to said turntable.

29. A rotary table as recited in claim 26 wherein said turntable includes a receptacle positioned near a periphery of said turntable for receiving said probe in an initialization procedure for locating said turntable relative to said probe apparatus.

30. A rotary table as recited in claim 26 wherein said turntable includes a receptacle positioned near the center of said turntable for receiving said probe in an initialization procedure for locating said turntable relative to said probe apparatus.

31. A rotary table as recited in claim 26 wherein said support base is coupled to a base of said probe apparatus such that a position and orientation of said rotary table is fixed relative to said probe apparatus.

32. A rotary table as recited in claim 28 wherein said probe of said probe apparatus is a stylus having a tip for contacting said object.

33. A method for locating the position and orientation of a rotary table with reference to a probe apparatus for measuring three-dimensional coordinates, the method comprising the steps of:

placing a probe of said probe apparatus in a receptacle positioned near a periphery of a turntable of said rotary table;

rotating said turntable while said probe is positioned in said receptacle;

sampling a plurality of positions and orientations of said probe as said turntable is rotated; and

determining the position and orientation of said rotary table relative to said probe apparatus utilizing said sampled plurality of positions and orientations of said probe.

34. A method as recited in claim 33 wherein said rotary table includes a sensor for detecting a change in angular rotation of said turntable when said turntable is rotated.

35. A method as recited in claim 34 wherein said probe is a stylus, and wherein said receptacle is a divot shaped to receive a tip of said stylus.

36. A method for developing a mesh representation of a three-dimensional object by a computer system, the method comprising the steps of:

receiving a data point from a probe corresponding to a surface point on a surface of a three-dimensional (3-D) object;

adding said data point to an end of a current contour line of a mesh representation, said current contour line including a plurality of data points corresponding to surface points on said surface of said 3-D object; and

creating a triangle in said mesh representation, said triangle including a data point of said current contour line, a data point of a previous contour line, and a third data point from either said current contour line or said previous contour line, wherein said triangle is created only when said current contour line is not the only contour line of said mesh representation.

37. A method as recited in claim 36 wherein said data point of said current contour line, said data point of said previous contour line, and said third data point are chosen based on the distance between data points of said current contour line and data points of said previous contour line.

38. A method as recited in claim 37 wherein said received data point, an index data point of said previous contour line, and a prior data point of said current contour line immediately previous to said received data point are included in said triangle when a distance between said received data point and said index data point is less than the distance between a next data point on said previous contour line immediately following said index data point and said prior data point.

39. A method as recited in claim 38 wherein said prior data point, said index data point, and said next data point are included in said triangle when said distance between said next data point and said prior data point is less than said distance between said received data point and said index data point.

40. A method as recited in claim 37 wherein said previous contour line is adjacent to said current contour line, wherein said data points of said previous contour line have been previously received from said probe.

41. A method as recited in claim 36 further comprising a step of assigning a normal vector to said triangle, said normal vector indicating an exterior surface of said mesh representation, wherein an orientation of said normal vector is based on orientation data included in at least one of said data points of said triangle.

42. A method as recited in claim 36 further comprising a step of displaying said triangle by drawing sides to said triangle between said received data point, said data point of said previous contour line, and said third point after said triangle is created.

43. A method as recited in claim 42 wherein said triangle and said mesh representation are displayed on a display screen coupled to said host computer.

44. A method as recited in claim 37 wherein said received data point is received by a host computer, and further comprising a step of providing said received data point to said host computer from said probe as a user is tracing said probe across said surface of said object.

45. A method as recited in claim 44 wherein said data point is provided to said host computer when a user control is activated.

46. A method as recited in claim 45 wherein said data point is provided to said host computer after said user traces said probe a minimum distance on said object.

47. A method as recited in claim 37 wherein when said received data point is a last data point of said current contour line, a triangle is created for each data point of said previous contour line that is not included in a triangle.

48. A method as recited in claim 37 wherein when said received data point is a second data point of said current contour line, a meshing direction is determined from said previous contour line and said current contour line, said meshing direction indicating from which end of said previous contour line to start creating said triangles.

49. A method as recited in claim 40 wherein said data points of said current contour line and said previous contour line are received successively along each respective contour line.

50. A method for assembling a linkage assembly including a plurality of joints and a linkage used in a probe apparatus for measuring three-dimensional coordinates, the method comprising the steps of:

providing two joint fixtures positioned a desired distance apart and having a relative orientation with respect to each other;

placing a joint of said linkage assembly in each of said joint fixtures, wherein said joints are moved relative to a linkage connecting said joints so that said joints fit in said joint fixtures within desired tolerances; and

bonding said joints to said linkage while said joints are placed in said joint fixtures.

51. A method as recited in claim 50 wherein said linkage is made of graphite.

52. A method for providing a selection template for receiving commands from a probe apparatus used for measuring three-dimensional coordinates, the method comprising steps of:

defining a template area within a selected volume as said selection template, wherein a stylus included in said probe apparatus is movable within said selected volume;

defining a selection area within said template area and associating said selection area with a command to a host computer coupled to said probe apparatus; and

providing said command associated with said selection area to said host computer to select a function of said host computer or of said probe apparatus, wherein said command is provided when said probe of said probe apparatus is positioned within said selection area.

53. A method as recited in claim 52 wherein a plurality of selection areas are defined within said template area, each of said selection areas being associated with a different command.

54. A method as recited in claim 53 wherein at least one of said selection areas includes indicia describing said command provided by said selection area.

55. A method as recited in claim 54 wherein said indicia in said selection areas include icons and labels.

56. A method as recited in claim 52 wherein said probe is a stylus having a tip, such that said command is provided to said host computer when said tip of said stylus is within said selection area.

57. A method as recited in claim 56 wherein said probe apparatus includes an arm linkage assembly having a plurality of joints and a plurality of linkages connecting said joints, wherein said stylus is positioned at one end of said arm linkage assembly.

58. A method as recited in claim 53 wherein said probe apparatus is operative to digitize a three-dimensional object into a geometric representation of said object when said object is traced with said probe, said geometric representation being developed by said host computer from data provided by said probe apparatus.

59. A method as recited in claim 58 wherein said command includes a command to manipulate said geometric representation of said object.

60. A method as recited in claim 59 wherein said geometric representation is a mesh representation.